Universitat Politècnica de Catalunya

Master's degree in
Numerical Methods in Engineering

Computational Mechanics Tools

Simulation Project

Building Subjected to Wind Loads

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1 Introduction

A frame building subjected to wind loads has been analysed using the simulation program ABAQUS. To get the results, the geometry of the problem was drawn and the material was assigned to the geometry. The load cases and boundary conditions were defined as stated in section 2 of this report. The structure meshed using linear beam elements and the results for the static and dynamic cases were computed. For the static analysis, the variables studied have been the displacements, von Mises and axial stresses and bending moments. For the dynamic analysis, the frequency modes of the structure were computed using the Lanczos Eigensolver. The results have been compared to the standard admissible values for each variable in order to compute the safety factor of the structure and verify if it will be able to support the loads without collapsing.

2 Problem statement

In this project, a frame building is studied for both a static and dynamic analysis. The building in question is shown in figure 1:

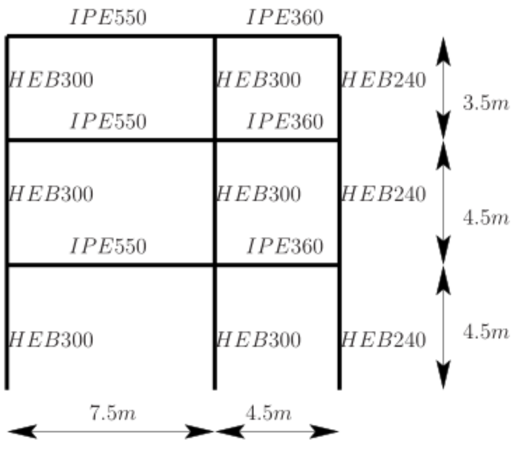


Figure 1: geometry of the problem.

Beam profiles are already defined by the European standard, so the properties are predefined and taken from tables (B2BMetal 2014a; B2BMetal 2014b).
In the static analysis, two loading cases are proposed, both shown in figure 2:

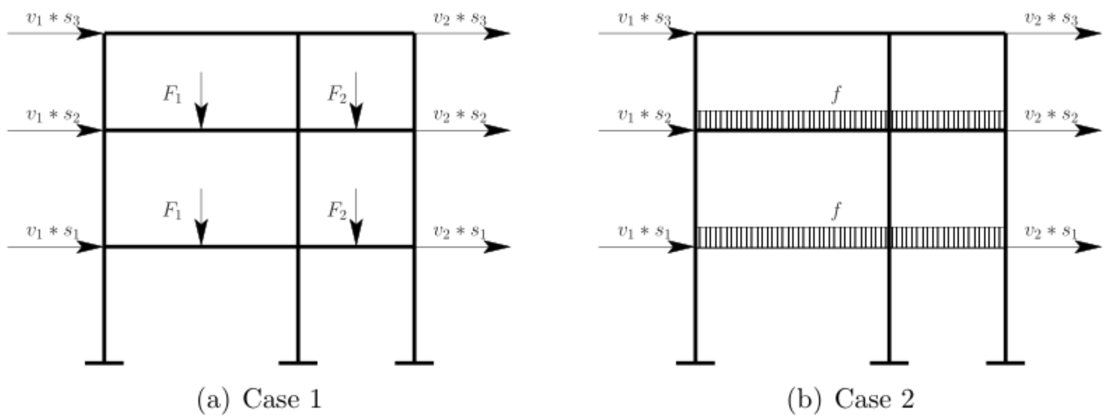


Figure 2: loading cases in static analysis.

These two cases represent two different ways of approaching the loading in slabs. Case 1 is easier to input, while case 2 is a more realistic approach. Both cases will be compared in order to see the differences. The wind load is applied as a point load in each floor, using a tributary area associated with the floor, while the base wind pressure is supposed as constant in all the face of the building subjected to it.

3 Methodology

The problem is implemented as it was shown on the tutorial through the course. The fist task is to set the units to be used. In this case, dimensions are measured in mm and forces in N. This is done in order to work stresses in N/mm^2, which is equivalent to MPa, the standard values of the industry. Once that is defined, the geometry is sketched in Abaqus with the dimensions supplied. During this stage a feature is introduced, dividing the beams corresponding to the floors, in order to apply the centered force later. Then, the material was defined. In this project the steel selected has the following properties:

Property	Value
Density	$7.85{\cdot}10^{-9}\ kg/mm^3$
Young Modulus	200 GPa
Poisson ratio	0.26
Yield Stress	275 MPa

Table 1: Dynamic analysis for Case 1 with hinged supports

The properties for the material were selected in order to closely match the properties of structural steel S275J2H, a conservative choice for building construction (SteelNumber 2017; SteelConstruction.info 2017). In order to continue defining the geometry, profiles are defined given the properties for the steel sections already defined, and then these are assigned to sections, in order to define which frame corresponds to each profile.
After the geometry is well defined, a dependent instance is created in order to apply the conditions and load cases, so after it is created the steps are defined: one static case with the basic properties and one frequency analysis in order to perform the modal analysis, where 10 modes are added.
After these steps are done, what's left is to define boundary conditions and loads to the problem. Constraints are applied to the footing of the building, considering both the clamped and hinged type of restraint in order to make the comparison. The load cases are applied to the corresponding nodes and frames which finishes the definition of the model.
To finish the modeling part and perform the analysis, the structure is meshed setting standard linear beam elements for all the frames, using a shear-flexible approach. The seed size is defined as 0.1 fraction of the global size. Now, the job is complete and the corresponding field output request are set in order to visualize the results.

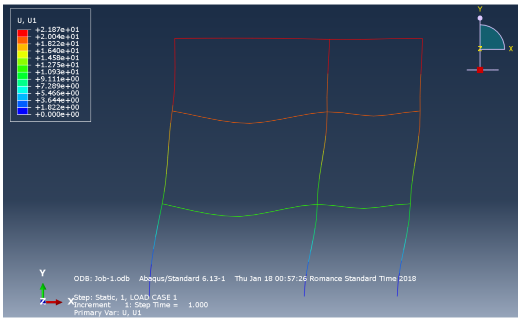
4 Results and discussion

The results are analyzed by load case:

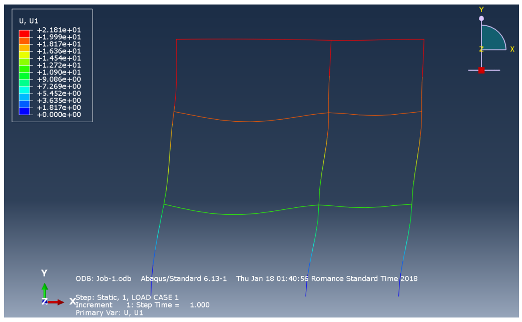
4.1 Static analysis

4.1.1 Horizontal displacements

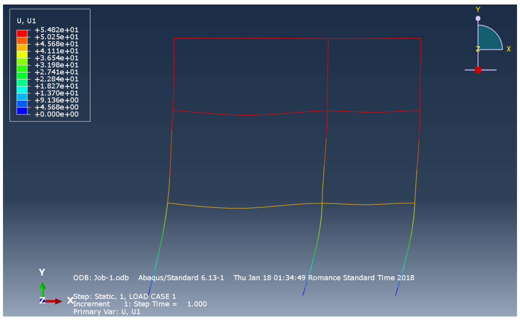
The results for displacement in both cases, with different restraint conditions are shown below:



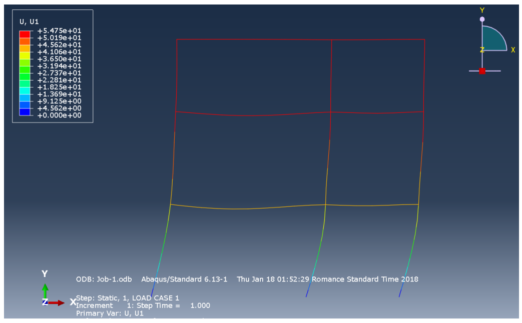
(a) Case 1, clamped.



(b) Case 2, clamped.



(c) Case 1, hinged.



(d) Case 2, hinged.

Figure 3: comparison of horizontal displacements.

In here we can see that the maximum displacement always occurs at the top right part of the building, which is the expected behavior due to how the forces are applied. The value is in the order of centimeters, which seems to be low for the size of the building. In order to do a numerical analysis of the displacement, a safety factor is computed for the four cases, considering the admissible displacement as 0.5% the height of the structure ($\delta_{adm} = 0.005H = 62.5mm$). With this, the safety factors are computed:

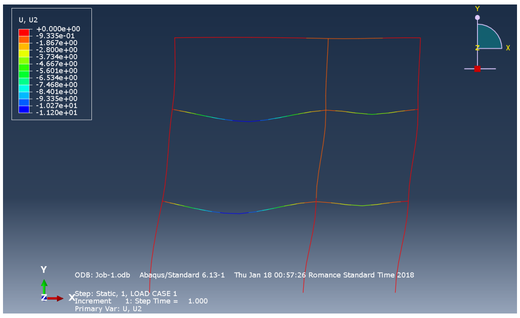
	Case 1, clamped	Case 1, hinged	Case 2, clamped	Case 2, hinged
Max. displacement (mm)	21.87	54.82	21.81	54.75
Safety factor	2.86	1.14	2.87	1.14

Table 2: comparison of safety factors for the four cases.

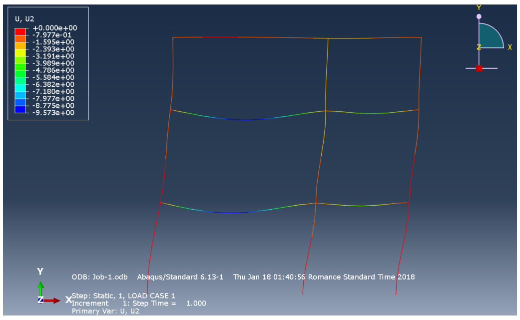
As an obvious result, it is seen that the displacements for the hinged case are much bigger than the ones for the clamped one, which is due to the fact that the structure is allowed a bigger degree of movement than the clamped case. Checking the safety factor associated to this displacements it is noticeable that the values for the hinged case are close to the unity, which could make the displacements unacceptable for the design. It is worth mentioning that the admissible value is not limited by the strength of the building, but as a way to keep the building inside livable limits of deformation, as well as for avoiding eventual crashes between buildings that are very close together.

4.1.2 Vertical displacements

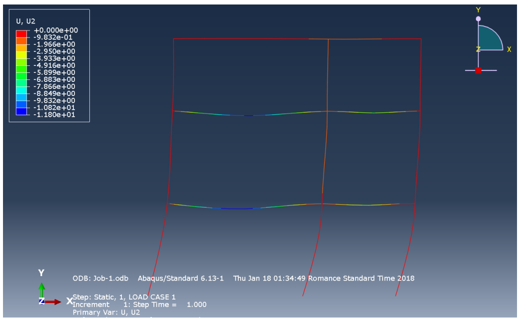
The same exercised is repeated for the vertical displacements:



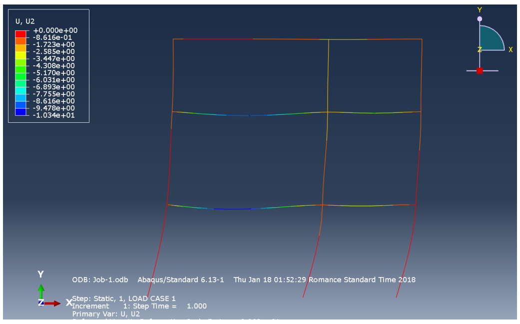
(a) Case 1, clamped.



(b) Case 2, clamped.



(c) Case 1, hinged.



(d) Case 2, hinged.

Figure 4: comparison of vertical displacements.

The maximum vertical displacement always occurs in the beams, particularly the ones in the longer span. This is expected since deformation in beams is square dependent on the length of it. Because of this, the analysis is focused on this beams. For a beam to be admissible there is no restriction in deformation, but for livable conditions some restrictions are imposed in deformation. For the safety factor here the admissible deformation is set as the 480th part of the length of the beam ($\ell/480 = 15.63mm$), which is the minimum perceptible descent. With this, the factors are computed:

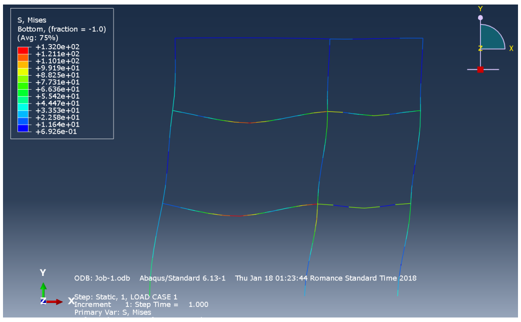
	Case 1, clamped	Case 1, hinged	Case 2, clamped	Case 2, hinged
Max. displacement (mm)	11.20	11.80	9.57	10.34
Safety factor	1.40	1.32	1.63	1.51

Table 3: comparison of safety factors for the four cases.

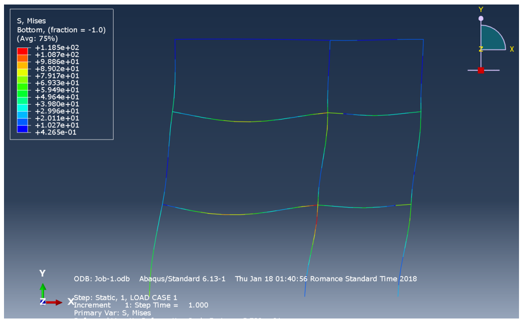
In here a more balanced distribution of values is seen, but it comes to attention the fact that the deformations are smaller for case 2, which is due to the fact that the forces in case 2 are bigger than the others, mainly because of the inclusion of live loads, which are not considered in case 1. If the distributed force is multiplied by the length of the beam gives 469.8 kN, significantly bigger than the 324 kN considered in the point load. In any case, it is possible to see that a distributed load is more "efficient", since it uses the whole length of the beam for the resistance and is not submitting a portion of it to stress.

4.1.3 Stresses

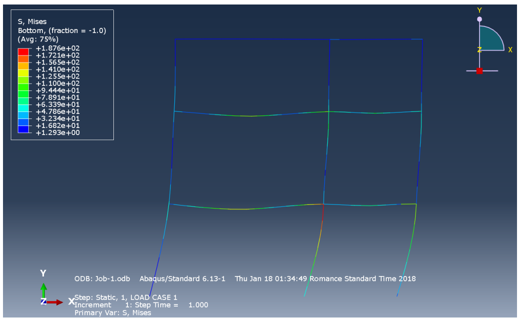
The Von Mises stress criteria is analyzed to see if there is failure in the building. The results are shown below:



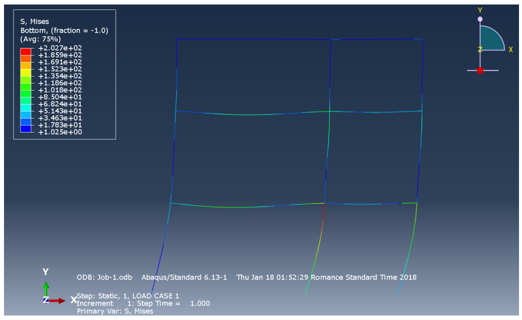
(a) Case 1, clamped.



(b) Case 2, clamped.



(c) Case 1, hinged.



(d) Case 2, hinged.

Figure 5: comparison of Von Mises stresses.

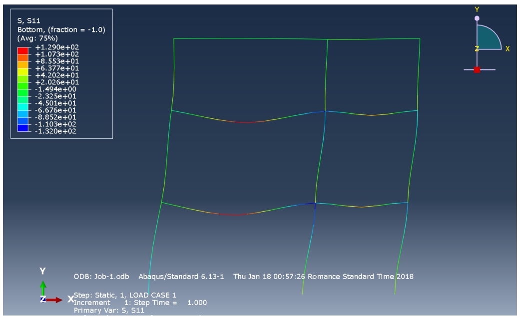
Since Von Mises is an squared average of stresses in the principal directions, the values of this field will always be positive. Also, because of this the comparison can be directly made between the yield stress and the Von Mises stress, in order to obtain the safety factor. The table below shows the safety factors for the yield stress defined in the material

	Case 1, clamped	Case 1, hinged	Case 2, clamped	Case 2, hinged
Max. Stress (MPa)	132	118.5	187.6	202.7
Safety factor	2.08	2.32	1.47	1.36

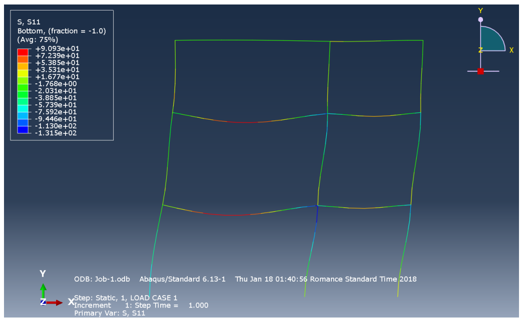
Table 4: comparison of safety factors for the four cases.

Here it is shown what was mentioned in the previous point. For point loads the effect is more localized, which raises the stress values, and it is noticeable that the points of mayor stress for case 1, at least in the clamped version, are occurring in the part where the load is applied. This phenomenon of concentration of stresses is well known in material science, which is why point loads are typically avoided or distributed to some degree. In any case, comparing the safety factor it can be concluded that there is not a pattern or trend to follow, since case 2 has lower safety factor due to the increased loads, but for hinged or clamped cases nothing can be said about it.

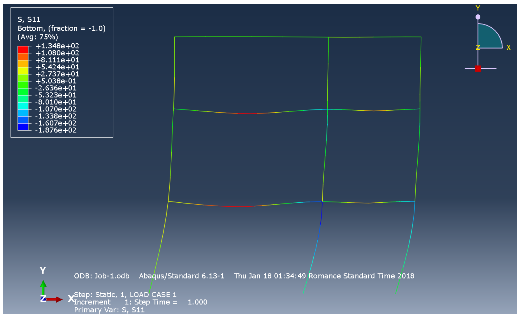
The axial stress is also considered in the analysis:



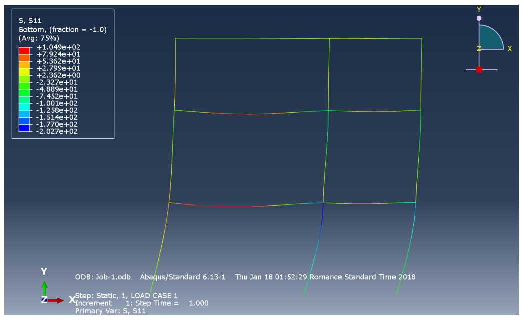
(a) Case 1, clamped.



(b) Case 2, clamped.



(c) Case 1, hinged.



(d) Case 2, hinged.

Figure 6: comparison of axial stresses.

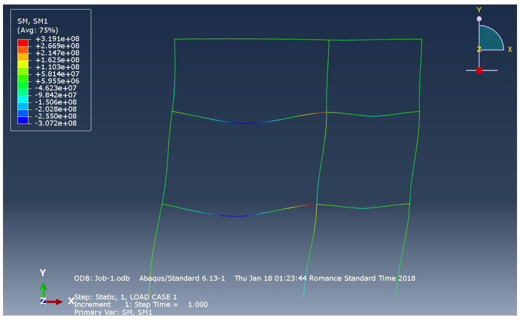
Again, since this is a stress value can be compared against the yield stress directly to obtain the safety factor, However, in this case there are two cases to analyze, since there are compressive stresses, as well as tensile ones. Considering this, the results are shown below:

	Case 1, clamped	Case 1, hinged	Case 2, clamped	Case 2, hinged
Max. Stress (MPa)	129.00	134.80	90.93	104.90
Safety factor	2.13	2.04	3.02	2.62
Min. Stress (MPa)	-132.00	-187.60	-131.50	-202.70
Safety factor	2.08	2.32	1.47	1.36

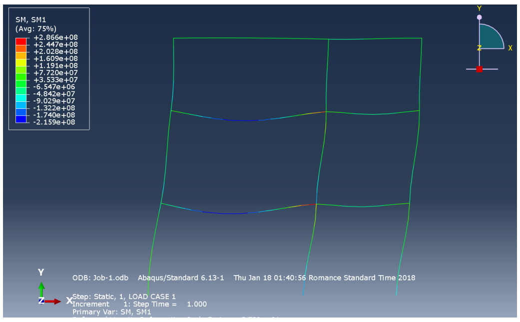
Table 5: comparison of safety factors for the four cases.

Again for axial stresses there is no major effects of the boundary conditions in the problem, and as expected stresses are bigger in case 2. Compression stresses are bigger than tensile ones, and the minimums are obtained in the base column, which support the weight of the whole building. As for the tensile stresses, the maximums are obtained in the beams due to the traction occurred at the time of bending.

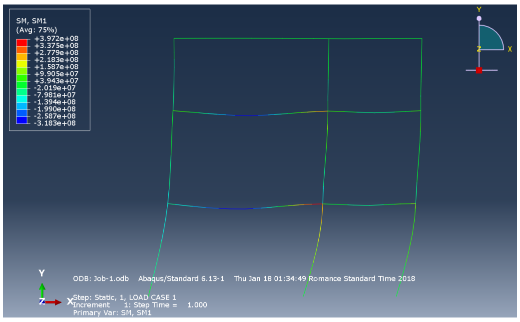
Finally, the internal moment is also shown:



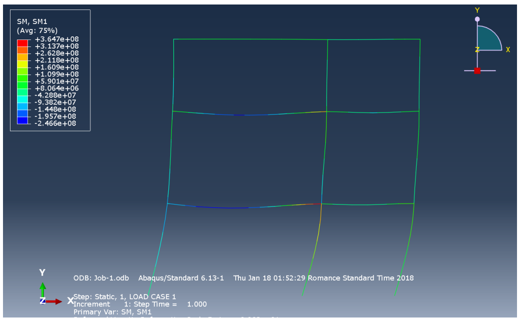
(a) Case 1, clamped.



(b) Case 2, clamped.



(c) Case 1, hinged.



(d) Case 2, hinged.

Figure 7: comparison of internal moments.

For this case, the comparison is not so direct. Since we have momentum values and not stresses, these values have to be converted. In order to do this, the section modulus of the beams are used to obtain a yield moment instead. These values are obtained from the same tables where the dimensions are get (B2BMetal 2014a; B2BMetal 2014b):

Profile	W_x (mm^3)	M_y $(N \cdot mm)$
HEB240	$9.38{\cdot}10^5$	$2.58{\cdot}10^8$
HEB300	$1.68{\cdot}10^6$	$4.61{\cdot}10^8$
IPE360	$9.04{\cdot}10^5$	$2.49{\cdot}10^8$
IPE550	$2.44{\cdot}10^6$	$6.71{\cdot}10^8$

Table 6: section modulus and yield moments for profiles.

With these values then he comparisons are made. Visually inspecting the images it is seen that most of the elements remain in the green color range, which values are well below the admissible values shown in the table. Because of this, only the critical profiles are studied, which are the first floor beam and the middle column at the bottom. The values are compared to the admissible moment and a safety factor is obtained:

	Case 1, clamped	Case 1, hinged	Case 2, clamped	Case 2, hinged
HEB300 max moment $(N \cdot mm)$	$1.63{\cdot}10^8$	$2.78{\cdot}10^8$	$1.61{\cdot}10^8$	$2.28{\cdot}10^8$
Safety factor	2.84	1.66	2.87	2.02
IPE550 max moment $(N \cdot mm)$	$3.19{\cdot}10^8$	$3.97{\cdot}10^8$	$2.87{\cdot}10^8$	$3.65{\cdot}10^8$
Safety factor	2.10	1.69	2.34	1.84
IPE550 min moment $(N \cdot mm)$	$-3.07{\cdot}10^8$	$-3.18{\cdot}10^8$	$-2.16{\cdot}10^8$	$-2.47{\cdot}10^8$
Safety factor	2.19	2.11	3.11	2.72

Table 7: comparison of safety factors for the four cases.

This is an important result since moment diagrams are essential to structural design, as they are the ones used for deciding if the sections used are optimal or not. In this case it is observable that the safety factors are very conservative as the values are high enough to suggest that the profiles will never reach the yielding point. Here a trend is established and it is seen that structures with clamped footing behave better than the hinged ones, probably due to its reduced motility, which induces less bending. What it is interesting to see, and is in line with the thing said is the fact that moments in case 2 are smaller than case 1 even though the forces are bigger, which is a direct consequence of the concentration of stresses mentioned before.

4.2 Dynamic analysis

Dynamic analysis is performed also in the structure in order to check how it behaves with respect to the frequency of the wind. For the first case of load, the values of natural frequencies of the building are obtained for both cases of restraints, and shown in tables 8 and 9:

Mode	Value	Frequency (Hz)
1	965.01	4.9441
2	11166	16.818
3	34921	29.742
4	58608	38.530
5	76105	41.849

Table 8: Dynamic analysis for Case 1 with clamped supports

Mode	Value	Frequency (Hz)
1	371.91	3.0693
2	7149.5	13.457
3	32599	28.736
4	57340	38.111
5	66032	40.897

Table 9: Dynamic analysis for Case 1 with hinged supports

As can be seen from here, the frequencies of the building are higher than the expected frequency of 2 Hz of the wind, so there is no risk of resonance. This results was expected given the flexibility of the structure, which gives higher natural frequencies compared to the relatively low frequency of the wind.
For case 2 the values obtained for frequencies are the same, and this is because the modes of a structure are dependent on the mass and stiffness of the structure (oversimplifying, frequencies are given by the relation $\sqrt{k/m}$). Since here in this case we are not defining dead loads as such, there is no variation in this aspect. It is important to note that in real analysis, permanent loads are accounted for the computation of the modes, since they behave as an added mass.

5 Conclusions

A typical frame building was analyzed in Abaqus for two different load cases in two different settings each, in order to see the behavior and compare which is the most efficient way of design. After getting the results and comparing them, it is appreciable that in general, the structure behaves well for all four settings and that collapse is not an imminent risk with this profiles. Clamped footings are better for the design of the building, since they reduce motility of the structure, effectively lowering deformations, and thus also reducing the bending moments in beams and columns. However, it has to be considered that in real life it is more difficult to have a completely clamped case, even more for steel structures, since it is difficult to restrain the rotation of the base of the columns in its totality.
For the dynamic case it was appreciated that resonance is not a problem, since the structure is flexible enough to have higher frequencies than the one expected for the wind. For both cases the frequencies were the same, which was expected but not too realistic, since dead loads should have been considered as added mass, and this affects the values of the frequencies.

For future work, several things could be improved:

- Safety factor in reality are never set to one for admissible value since it is too close to failure. Typical values for safety factor range from 1.5 to 3, values which in much of the cases shown the structure would have failed.
- Wind is not correctly displayed on the cases. Point loads are an easy way to set them, but distributed loads are more realistic. Also, wind forces should be tested in both directions, specially in asymmetric buildings as this one.
- Distributed loads should be preferred to point loads when considering beam loads, but this are slightly more difficult to study when a fast analysis is done.
- Optimization of the profiles of the building is desired, since steel is an expensive material and much of the profiles of the building are severely understressed.

References

B2BMetal (2014a). *HEB BEAMS, EUROPEAN STANDARD WIDE FLANGE H BEAMS, DIMENSIONS, SPECIFICATIONS. HE B BEAMS IN ACCORDANCE WITH FORMER STANDARD EURONORM 53-62*. URL: http://www.b2bmetal.eu/heb-sections-specification (visited on 01/14/2018).

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Appendix

The project work has been splitted such as each one of the team members was in charge to build and run one case. The analysis of the results was mainly done by Gabriel Valdés Alonzo, since he has a background in Structural Engineering.